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Radio Astronomy: Clark SRT Restoration

PJ Rioles
Clark University, PRioles@clarku.edu

Jacob Vider
Clark University, jvider@clarku.edu

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PJ Rioles ’22 & Jacob Vider ’22 – (Sponsor: Professor Charles Agosta)

CLARK UNIVERSITY

Introduction

Astronomy, the study of celestial objects including planets, stars, galaxies, dark matter, and dark energy, has intrigued minds throughout history. The earliest written records ever discovered were astronomical observations from the Babylonian civilization consisting of positions of planets, times of eclipses, etc. dating back to roughly 1600 B.C.. Six hundred years later, ancient Greeks compiled the Babylonian’s data and constructed an astronomical framework which identified patterns in the sky that could be used for celestial navigation or eventually experiments designed to investigate the size and distance of celestial objects, as well as prove the spherical shape of Earth. In 270 B.C. Aristarchus conceived the first notion of a heliocentric solar system, in 100 B.C Hipparchus compiled the first known catalog of names and positions of the constellations. Even after almost all written records of astronomical observations, data collection, and calculations were destroyed in the Great Library of Alexandria in 272 A.D., the field endured. Copernicus picked up where Aristarchus had left off, challenging the geocentric doctrine of the Catholic Church with his reinvented heliocentric solar system model in the 1500s. Next came the first observatory and modern database of celestial measurements from Tycho Brahe in 1580, paving the way for Kepler’s Laws of motion, Galileo’s laws of motion, and the invention of the telescope. With the addition of Newton’s laws of gravitation in the 1680’s, the astronomical field of the present is beginning to take shape. [1] However, to capture the full image, the field still requires some extra light to be shined upon it… wavelength may vary.

Most commonly, astronomy is imagined as the study of our universe in visible light or light our eyes are capable of perceiving. However, there are other wavelengths within the electromagnetic spectrum which have frequencies above and below what is detectable by the human eye. These invisible spectra include gamma rays, x rays, ultraviolet, infrared, and radio waves. Each wavelength provides a unique perspective in which distinct astronomical observations and analysis can be made (**Fig 1**), with radio astronomy being among the most widespread alternatives to visible light astronomy due to its versatility and profound applications. [2] Benefits of radio astronomy include its independence to interference from light pollution, and its disregard for atmospheric conditions due to its longer wavelength which allows the electromagnetic wave to penetrate through dust, and water vapor. [3] Along with the practical utility of using radio waves for astronomical observations, the radio spectrum can unveil aspects of the Universe which are hidden from even the other wavelengths of light. Just two years ago, Katie Bowman and the Event Horizon Telescope Team worked with arrays of radio telescopes from around the world in order to create a global array of interferometers, effectively creating a radio telescope with the diameter of the Earth. This massive virtual diameter dramatically decreased the angular resolution of the EHT, allowing the team to measure the radio waves emitted from the accretion disk of the M82 X-1 x-ray source and render the first image of black hole. (**Fig 2**) Radio astronomy has allowed the field of astronomy to further develop and improve, solving questions, raising more.

The purpose of this research project is to repair, rebuild, and upgrade Clark University’s Small Radio Telescope (SRT) in order to provide the university’s faculty, researchers, and students with the opportunity to peek behind the curtain and view the hidden wonders of our universe. The SRT is in need of mechanical and electronic repair, as well as a software modernization.

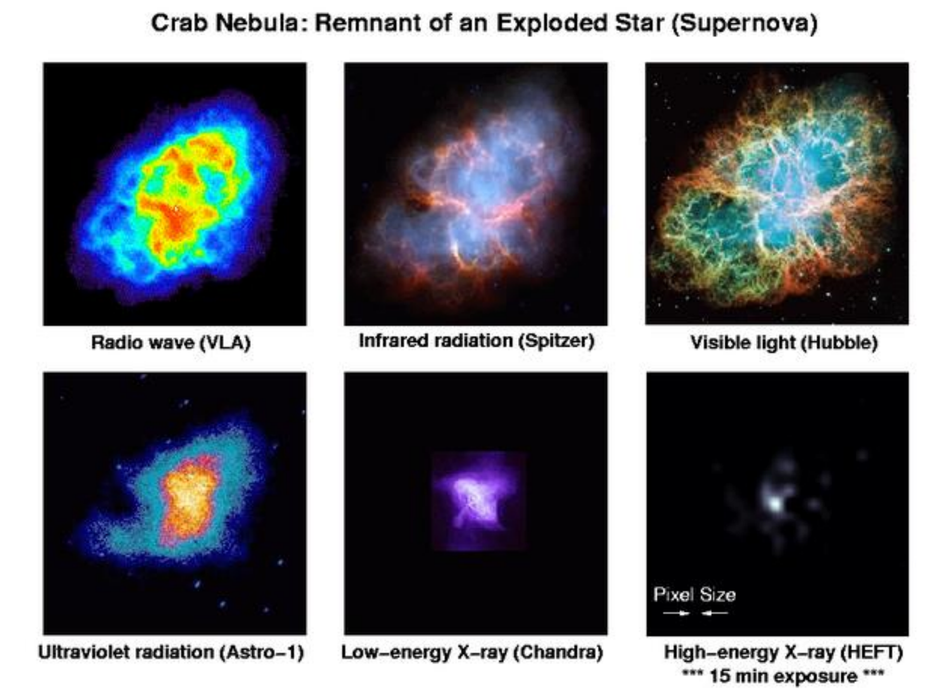

Fig 1: Crab Nebula stellar remnant imaged in six different wavelength of light.

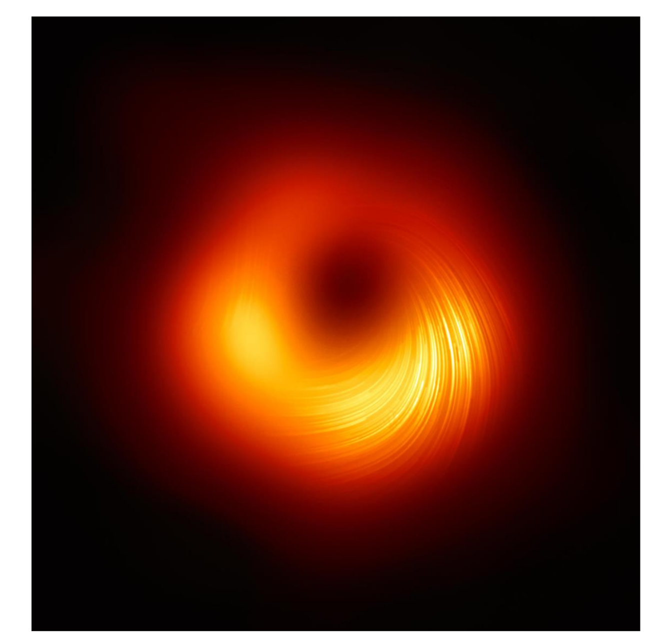

Fig 2: Second iteration of the M82 black hole image where the polarization of the object’s magnetic field was captured.

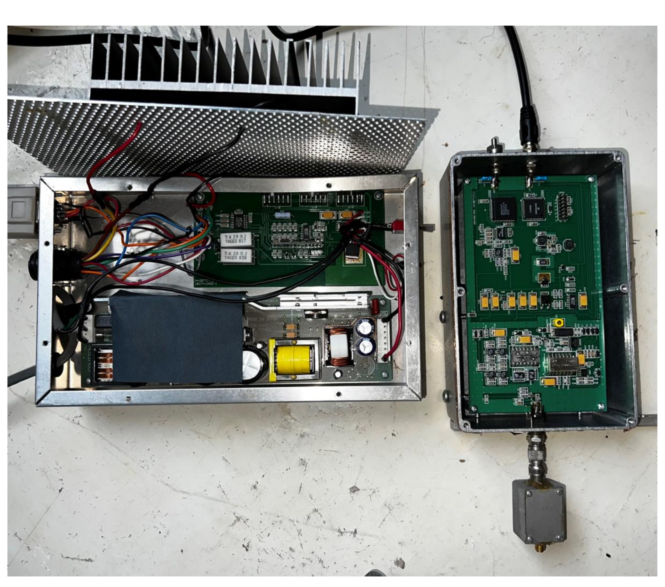

Fig 3: Telescope control box (left) connected to Digital Receiver/Signal Processor (right)

Hardware

Clark’s SRT is a 3-meter diameter parabolic satellite dish, fitted with a digital receiver which uses a series of low pass filters, amplifiers, mixers, and a local oscillator to refine the received frequency, at which point the resulting RF is input to the digital signal processor. The signal processor performs a discrete Fourier transform is to get an accurate spectrum of the signal around the 1.42 MHz base frequency of the SRT. (**Fig 3**) The motion of the dish is controlled by a dual stepper motor drive system: a linear actuator which allows the dish 90 degrees of elevation from the horizon, and gear box motor mount which allows 360 degrees of movement along the azimuth. The telescope is controlled entirely through software which communicates with the telescope through a control box via a RS-232 serial connection (**Fig 3**). The control box is wired directly into the two motors and the digital receiver. [4]

Hardware Repairs

Drive System:

The chain inside the azimuth motor mount was continuously jamming and/or slipping off its gear. (**Fig 4**) In order to fix this issue, the motor mount was modified so that the two gears which drove the chain were properly aligned.

The arm of the linear actuator was immobile due to weathering and rust, in an effort to fix the issue the actuator was disassembled, cleaned, and reoiled. The arm was now free; however, the motor still struggled to extend or retract it.

Electronics:

Wiring within the azimuth motor mount (**Fig 4**), linear actuator (**Fig 6**), and nine-pin connector that communicates from the control box to the telescope were all corroded and needed to be completely rewired. The corrosion also spread into the linear actuator’s electric motor destroying one of the motor’s carbon brush contacts. It is being replaced and will likely solve the laboring motor issue. (**Fig 6**)

Parabolic Satellite Dish:

The dish was missing an entire mesh “petal” which was replaced by sourcing mesh from another satellite dish of the same diameter and fixing the replacement mesh to the chassis of Clark’s dish. (**Fig 5**)

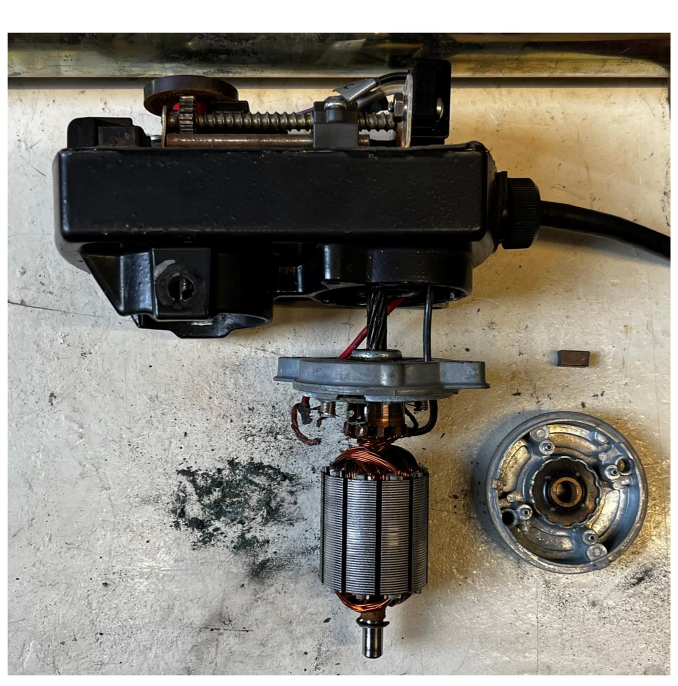

Fig 6: Disassembled Linear Actuator Motor and Electronics Housing

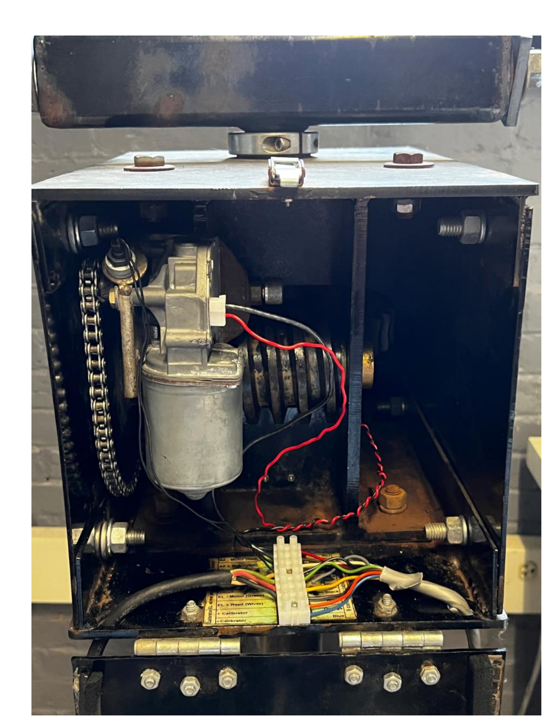

Fig 4: Rewired Cassi Corp. Azimuth Motor Mount

Fig 5: Repaired Mesh Satellite Dish

Hydrogen Hyperfine Transition

Atoms can exist in different energy states dependent on the energy level of the atom’s electrons. However, more discretely, there is a phenomenon called hyperfine splitting where the ground state of an atom is divided into distinct hyperfine levels which are separated by one millionth of an eV and are a result of opposing spin states of the electrons and the nucleus of the atom. Hydrogen has two possible spin states, spin parallel and spin anti-parallel. Once a hydrogen atom relaxes from its excited hyperfine state, it releases a 21cm or 1420 MHz radio wave which Clark’s SRT is able to detect. [5] (**Fig 7**) On average one radio emission occurs every 10 million years, however, hydrogen is the most abundant element in the universe. Given the angular resolution of the Clark SRT for one light year of space, there would be a flux of $2.5\ 10^{33}$ hydrogen radio emissions. The immense presence of hydrogen and its large photon flux throughout the universe allows radio telescopes to analyze virtually any location in space, and the frequency of the emitted photon is incredibly constant meaning any detectable change in received frequency indicates a difference in velocity of the region of space where the frequency was measured with respect to Earth.

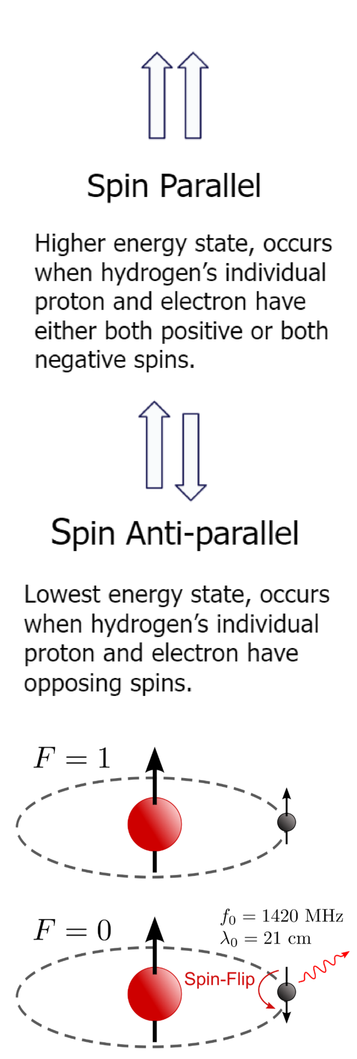

Fig 7: 21cm Hydrogen Emission

Software

Currently the Clark SRT is still operating under the original java code written and distributed by MIT. The code runs and controls the telescope properly offering features such as an interactive sky map, a track feature to maintain a position lock with an object, and manual azimuth and elevation controls giving users freedom to take measurements from anywhere in the sky. However, the code is forcing the project to run on an outdated computer due to an incompatibility with newer versions of MacOS, so ideally the telescope will switch to the updated MIT java code, MIT C code, or the adapted C code written by Clark students. [6]

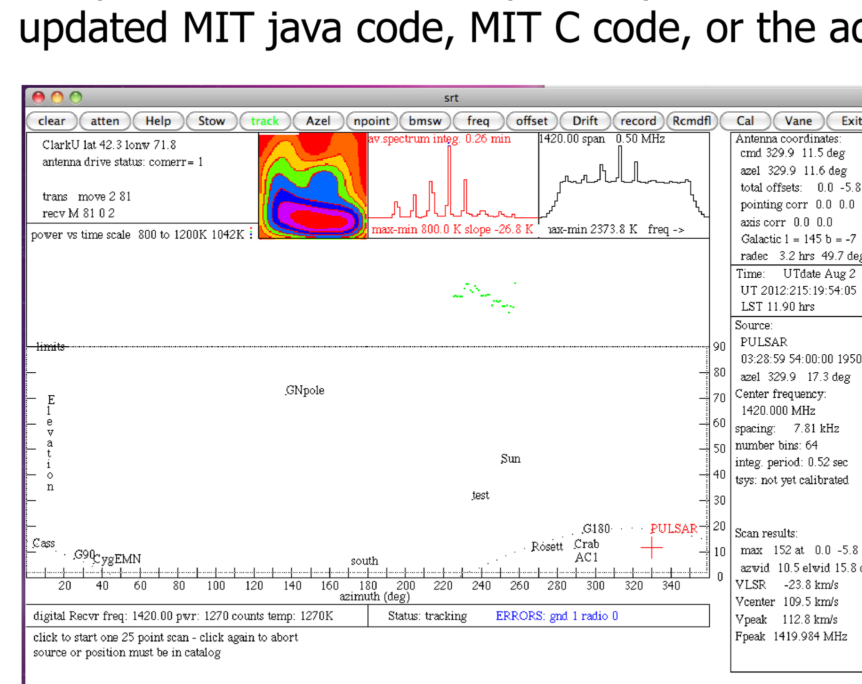

Fig 8: Original MIT SRT Java Code GUI

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